V. TECHNICAL ACTIVITIES OF THE DRYLAND INITIATIVE

Technical work undertaken under the Dryland Initiative was principally carried out at the local scale and addressed issues that were highly relevant to local communities. Its focus was the local management of natural resources, and given the dryland conditions prevailing throughout all five partner countries, the management of scarce water resources assumed a central place in much of the applied and adaptive research carried out under the Initiative. As such, research and development in the two consolidated thematic areas "*Watershed Management*" and "*Treated Wastewater and Biosolids Reuse*" were in fact activities aiming at improved *Water Resources Management* which would attempt to increase the net availability of water (through water-harvesting and -storing technologies), improve water-use efficiency (drought- and salinity-adapted species and appropriate irrigation technologies), and recycle existing water sources (reuse of treated wastewater and biosolids in agricultural production).

A. The Watershed Management programs of the Dryland Initiative

Watershed management program activities were divided into five areas, themselves consisting of component items, some of which in turn consisted of individual technology packages. Thus conceived, the program assumed a taxonomy that is best represented in outline form, and described in detail in the sections that follow (also see Figure 43).

1. *Increasing water availability through Water Harvesting and Storage*
   a. Water harvesting and soil water storage
   b. Water storage in wells, cisterns, and rehabilitated springs
2. *Crop production and rangeland management*
   a. Improved agro-technical packages for cereal production
   b. New fodder crops on rangeland
   c. Approaches to reduce grazing pressure
3. *Fruit and non-fruit tree cultivation*
   a. Tree crops and tree-field crop intercropping
   b. Fuelwood production
   c. Afforestation and carbon sequestration
   d. Sand-dune fixation
4. *Genetic resources and biodiversity*
   a. Plant biodiversity surveys
   b. Ex-situ genetic resource facilities, including genebanks, botanical gardens, and nurseries
   c. In-situ biodiversity conservation and eco-tourism protected areas
5. *Diversifying farming systems and promoting off-farm activities*
   a. Socio-economic analyses
   b. Non-conventional crops
   c. Dairy production

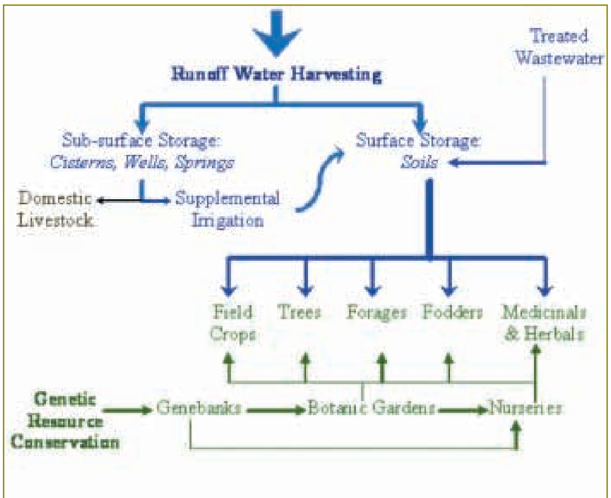

Figure 43: Watershed Management.

Increasing Water Availability through Water Harvesting and Storage

Water harvesting *techniques* developed and/or tested under the Initiative included three types of *contour ridges* and *terraces* which were constructed and tested for their effectiveness in rehabilitating rangelands and supporting a variety of crops, forages, and stabilizing plants. Earthen contour ridges constructed on sloping surfaces with ditches dug along the upslope sides were designed principally to rehabilitate degraded rangelands. The ditches served as sinks for runoff generated by the sloping surface between two successive ridges. The water stored deep in the soil supported a variety of bushes, trees, and forages planted along the ditches. In two Jordanian demonstration sites at Mohareb in the Muaggar area and Sabha in the Mafraq area, local bushes of the genus *Atriplex* cultivated along these ridges covered 2,500 hectares. Spillways were repaired as necessary after each rainy season and ridge-supporting bushes that did not survive were systematically replaced (Figures 44, 45, 46)

Another type of large scale earthen contour ridge was constructed on slopes with relatively more gentle gradients, and was used to slow down rather than concentrate runoff flows. The flows were spread over the surface between two successive ridges, and

Figure 44: Gullies and large-scale earthen ridges in an Egyptian watershed.

Figure 45: Contours, terraces, and gullies in sloping arid drylands; Israel.

Figure 46: Large-scale contours and terracing in the West Bank semiarid drylands.

used to cultivate barley at the principal Egyptian Watershed Management site in the upper Wadi Um Ashtan. At the Jordanian Watershed Management site in the upper Wadi Mujib, deep soil ripping was introduced to the contour areas to improve water infiltration, and resulted in markedly increased forage production (Figure 47). The Jordanian Watershed Management team calculated the returns from the increased production to be 50 percent higher than the cost of constructing and maintaining the contour ridges.

The third type of large scale structure consisted of a system of *contour terraces* that were constructed in lower areas of local watersheds. Permeable stone dykes built at the ends of tributaries and at the tips of wadis were used to support the terraces and to regulate water flows, spreading them down-slope

Figure 47: Contour "sinks" on gentle slopes in Jordan through deep ripping.

along the catchments of area foothills (Figure 48). The contour terrace systems were tested at the Egyptian Watershed Management site in the lower Um el Ashtan, and in wadis at six Palestinian project sites in the Hebron area. The Palestinian terraces were supported by 30 centimeter high rocky walls on the up-slope side, and by the tough, thorny *Sarcopoterium spinosum* on the down-slope side. These pillow-shaped bushes increased water holding capacity behind the terrace wall, on which olive saplings were planted and existing olive trees were monitored.

Structures known as "*micro-catchments*" were a smaller-scale technology introduced under the *water harvesting* components, and were used to support individual trees or small groups of trees (Figure 49). In the Egyptian Watershed Management site at Wadi Um Ashtan, diamond shaped pits for runoff harvesting were constructed in the upper reaches of the watershed (Figure 50), while semi-circular micro-catchments of between 100 and 120 square meters were constructed in the watersheds' lower reaches. These were used to grow fruit trees, often intercropped with vegetables. Measurements of the volume of runoff harvested in a given area would be used to determine the micro-catchment's size after experiments showed that a micro-catchment area 15 times the size of the crop target area is generally required to sustain crop production.

Figure 48: Contour terraces in a Wadi; West Bank.

Figure 49: Micro-catchments in Northwestern Egypt.

Figure 50: Rectangular ("diamond-shaped") micro-catchments, Hebron Region, West Bank (PNA).

The Palestinian Watershed Management team constructed diamond-shaped micro-catchments at eight sites to support almond, peach, apricot, and olive trees. Experiments carried out near the end of the Initiative compared these micro-catchments to the larger scale permeable stony terrace contours described above. The Tunisian team dug rows of pits in sandy soil to collect runoff for soil conservation purposes, and for use in supporting trees used for fuelwood.

The Israeli Water Management team used measurements of rainfall, runoff volume, and soil moisture to assess the efficiency of micro-catchments in supporting afforested trees. The assessment concluded that micro-catchment dimensions should be specifically tailored to site-specific slope and soil characteristics, rather than being uniformly applied and carried out using heavy machinery.

A new system of runoff harvesting was designed to support olive cultivation in areas that typically experienced about 100 millimeters of annual rainfall. The system consisted of trenches or ditches to reduce moisture loss from evaporation. The high cost of digging these trenches required the cultivation of high value produce, thus the focus on olives. The system was also used to test the resilience of water harvesting and storage to prolonged drought conditions in these areas. An inherent problem in channeling surface runoff to ditches for deep soil storage is the lateral dispersion of the water across the ditch's shallow subsurface before its downward vertical infiltration carries it to depths at which the moisture is no longer subject to evaporation.

Figure 51: Runoff conveyed to trench through pipe after going through a stilling pond. Mashash Experimental Farm, Israel.

Two approaches to reducing the evaporation of horizontally moving water were tested at the Mashash Experimental Farm and the Yatir site in Israel. The first approach involved alternative methods of ground cover, including plastic covers, crust-breaking, and mulching. The use of plastic covers proved more effective at reducing evaporation than crust-breaking treatments. The use of mulches to reduce evaporation loss at the Yatir site was found to have no significant affect on the growth of trees within the ditches. The second approach to reducing evaporation focused on increasing the runoff water's downward movement to soil depths exempt from evaporation. This involved deepening trenches to 1.2 meters, which significantly reduced shallow lateral movement and evaporation loss, increasing the amount of runoff water received by the trees five-fold._The canopy of trees planted at the bottom of the trench are expected to completely shade the deep pits once the trees are older, thus further reducing evaporation (Figure 51 and 52).

Figure 52: Increasing water storage by deep trenches, supporting olives at 100 mm rainfall; Mashash Experimental Farm, BIDR, Israel.

Finally, the Israeli Watershed Management team tested the potential of water harvesting for increasing soil water storage in arid areas in a context of prolonged drought. Between 1996 and 2000 the Mashash area experienced the longest drought recorded locally in the last 60 years. Soil moisture levels and productivity and mortality rates among olive and *Acacia saligna* trees were recorded. Most trees survived and damage was quite limited. Among the trees that did not survive however, no soil moisture was found in the root zones, suggesting that proper techniques of runoff harvesting can support economically valuable trees in arid areas *except* during rare cases of extremely severe droughts.

Water storage in wells, cisterns, and springs entailed the construction of new wells and cisterns as well as the rehabilitation of old (sometimes ancient) and abandoned wells and cisterns, and the restoration of neglected springs.

The Egyptian Watershed Management team took part in the construction of 20 meter deep cisterns, and in the rehabilitation of old sub-surface canals in the lower reaches of Wadi Um Ashtan. The additional surface and sub-surface runoff water stored was applied to crops on two demonstration sites using two methods of irrigation. On one site, cistern-stored rainwater was applied to wheat and barley crops mixed with acacia trees, using portable sprinkler irrigation. The other demonstration site applied groundwater pumped from a 20 meter well to winter vegetables intercropped with figs, using a drip irrigation system.

The Jordanian Watershed Management team took part in the construction of 37 shallower cisterns, between three and seven meters deep, at three demonstration sites in the upper catchments of the Wadi Mujib watershed (Figure 53). Construction was co-financed with 80 households in four villages near the Muhareb, Shoushan, and Kteifa demonstration sites. The cistern water was distributed between livestock (52 percent), domestic uses (28 percent), and supplemental crop irrigation (20 percent). Financial returns would be estimated at between 1.4 and 1.7 times the cost of cistern construction.

The Palestinian Watershed management team undertook a survey of 118 springs, cisterns, and wells extant within the Hebron area. 82 of these were selected for a detailed inventory of depth, flow rates, surrounding lithology, chemical composition, ownership, and water use (domestic, irrigation, and livestock). Chemical and bacteriological analysis was conducted on some 50 springs, 95 percent of which were found to be bacteria-contaminated to the point of posing serious risk to public health. The team concluded that most were however suitable for agricultural uses, despite high levels of nitrates and chloride in a number of the springs. The inventory was used to populate a database, which was in turn used to identify the three most promising springs for rehabilitation, which involved removing debris, replacing dilapidated structures, installing PVC pipes, and building protective concrete structures.

Figure 53: Runnoff collection in cistern; Jordan.

Field Crop Production and Rangeland Management

Crop production and rangeland management activities of the Initiative's Watershed Management program employed packages of improved technologies and practices to capitalize on the increased availability of water achieved through harvesting.

The Egyptian Watershed Management program introduced an agro-technical package of improved wheat and barley varieties fed by harvested runoff. The seeds were soaked and coated with bio-fertilizer containing microelements and nitrogen-fixing bacteria (Figure 54). Plots were tilled and fertilized with slow-release fertilizers. Grain and straw yields increased by 250 percent in the lower Um el Ashtan watershed, and by 50 percent in the upper watershed. Economic analysis found the market value added by the combination of the water harvesting structures and the application of the package was 30 percent higher than the cost of constructing the structures and purchasing the package, although some of the additional product was used on farm and never sold to market. Wheat production, principally for direct human consumption, increased as a result of the package's introduction. Barley production, entirely for fodder, increased as well, but not as much as wheat production. Yet barley production was more efficient in terms of resource use, and proved more profitable than wheat production. However, in order to provide sufficient household income from livestock production by growing enough supplemental feed to effectively reduce grazing pressure, the productivity of barley would have to increase to levels greater than those achieved by the project.

Figure 54: Improving cropland and rangeland productivity in Egypt.

National Watershed Management programs introduced new forage species to support livestock in rangelands that benefited from the local runoff harvesting efforts. These forages further encouraged measures to protect the rangelands from overgrazing. Range improvement activities on 72 *feddans* in Egypt and across 2,500 hectares in Jordan grew thousands of *Atriplex* seedlings in degraded rangelands which capitalized on local runoff harvesting. In Jordan, succulent leaf *Opuntia* cactus was also introduced in alternating "inter-ditch" strips of cactus and barley. In Egypt, exotic acacia species were introduced as well. Land owners were advised to refrain from grazing for several years until saplings were well established. The Jordanian team monitored rainfall, soil composition and moisture, and seedling survival and growth rates. The Egyptian team successfully promoted these fodders on the terraces of reclaimed wadis in conjunction with high-value horticultural crops at the wadi bottoms. The success notwithstanding, the team estimated that its range improvement efforts led to 10 percent increase in profits – far less profitable than investments in improved cereals or in olive cultivation in the same watersheds. Yet in both Egypt and Jordan, the shift from natural rangeland to a mixed rangeland–crop system increased carrying capacity and yielded higher net returns to farmers.

The Palestinian and Tunisian Watershed Management programs worked with very large numbers of forage and medicinal plants, including sea orach (*Atriplex halimus*), saltbush (*Atriplex nummularia)*, golden leaf wattle *(Acacia cyanophylla)*, and sturt's cassia *(Cassia sturtii)*. The Tunisians planted bushes and trees in pitted rows in sites from 6 to 300 hectares, and promoted their establishment with fertilization and irrigation with brackish water from adjacent wells. Seedling survival and growth rates were closely monitored, as was the degree of sand stabilization achieved. The activity brought about measurable regeneration of indigenous vegetation on degraded rangelands, and contributed to the stabilization of sandy soils (Figure 55). Livestock grazing and firewood collection were excluded from the plots by fencing and through agreements with local land owners. 150 families received 80 kilograms of barley a year as compensation, as well as a large number of olive tree seedlings.

The Jordanian Watershed Management team's work on rangeland management stressed alternatives to grazing, and its strategy to reduce grazing pressure included a co-financing arrangement with farmers owning fewer than thirty heads of livestock to construct animal shelters. The strategy also included supplementing or replacing grazing forages by providing fodders, both dry feed blocks and fresh opuntia cactus cladodes were cultivated in the runoff harvesting project (Figure 56). Several training events provided farmers instruction on the preparation of feed blocks using a variety of farm residues. The team was also involved in maintaining and monitoring government range reserves, and organized a number of "cut and carry" operations among local farmers, providing another source of fresh fodder.

Figure 55: Rangeland rehabilitation in Henchir Senoussi and Ouled Hfaiedh, Menzel Habib region, Tunisia. Overgrazed sandy rangelands (forefront) degraded into shifting sand dunes (background, right)

Figure 56: Opuntia cactus produced at eco-tourism site; Jordan.

Fruit and Non-Fruit Tree Cultivation

Dryland Initiative work on tree cultivation included ***fruit trees***, combinations of fruit and non-fruit trees, and intercropping fruit trees with annual crops. The Palestinian Watershed Management team selected a number of watersheds in which to test the effects of a novel run-off harvesting structure on nearby trees, both established and newly planted. The watersheds were selected on the basis of detailed soil chemical analyses and soil profiles which revealed evidence of soil degradation, low water holding capacity, and reduced infiltration – but also the availability of soil nutrients vital to the cultivation of trees. One-year old saplings of improved, drought-tolerant varieties of almond, apricot, peach, and fig trees were planted in ten sites. Four other sites with existing olive trees were also selected, and the 14 sites were used to test the efficiency of two water harvesting techniques in supporting the trees. The Israeli Watershed Management team monitored the long term responses of almond and pistachio orchards to floodwater harvested at an experimental farm at Avdat (Figure 57). The changes recorded in almond and pistachio yields were entered into a database that was used to collect information presented in Watershed Management training programs.

Intercropping fruit trees and annual crops is a particularly efficient practice in utilizing harvested

Figure 57: Run-off harvesting for tree cultivation. Almond trees on the Avdat Runoff Agriculture Demonstration Farm; Israel. Run-off generating area is the rocky slopes at the background. Small dykes (arrows) lead the runoff to the terraces.

and stored runoff. In the rainy season, topsoils are moist and water is readily available to shallow-rooted annual crops. In the dry season, topsoils are parched but the water stored in deeper soil layers is available to deep-rooted trees.

The Egyptian Watershed Management team intercropped fig and olive trees with tomatoes, onion, and faba beans on sites supported by both harvested water (stored in the soil), and water stored in shallow wells that was transported through non-pressurized drip irrigation (Figure 58). This method of supplemental irrigation increased water use efficiency among trees by between 50 and 60 percent, and raised fig and olive yields by between 60 and 70 percent. Water use efficiency among the intercropped vegetables increased by factors of between three and five, and yields were between 9 and 17 times higher than those achieved without irrigation. The investment in olive production was especially profitable, with returns projected at 11.5 times the cost of constructing and maintaining the runoff harvesting structures.

Israeli experiments at the BIDR Mashash farm intercropped olive trees and orange wattle (*Acacia saligna)* with English Sudan grass (*Sorghum vulgare*) and went on to achieve maximal non-competitive utilization of stored water throughout the soil profile (Figure 59). The Israeli Watershed Management team also experimented with an innovative runoff harvesting method for supporting olive cultivation in deep trenches. These experiments took place in the context of the extreme drought conditions described earlier under *Water Harvesting Techniques*, and were supported by a model that projected the trench runoff storage technology to be less successful than irrigation, but more successful than conventional rainfed olive cultivation.

Figure 58: Drip irrigation system, using pumped groundwater from a 20-meter deep well, used in winter vegetables intercropped with figs; Egypt.

Figure 59: Firewood and fodder trees. *Acacia saligna* is cultivated for perennial production of firewood. Regeneration following lopping. Runoff through a wadi bed is channeled to this run-off collecting enclosure circled by earthen dykes.

The Tunisian Watershed Management team planted olive trees in degraded sandy rangelands at low densities of between 17 and 20 trees per hectare. The low density sowing would enable the regeneration of indigenous pasture vegetation, thus promoting the transformation of the degraded range into a stable and sustainable sylvi-pastoral system.

Non-fruit bearing trees are important sources of fuelwood and fodders, and benefit soil conservation both directly and indirectly. Their direct benefits apply through the effects of their deep root systems and canopies, which protect soil from being swept away by floodwater and surface soil from being impacted by raindrop and eroded, respectively. Their indirect benefits relate to their role as fuelwood sources, which - sustainably harvested - can remove pressure from surrounding vegetation.

The orange wattle (*Acacia saligna*) tree used in the Mashash farm intercrop proved to be very efficient in producing high quality firewood in arid areas where concentrated runoff is sufficient to promote its post-harvest regeneration. This exotic (Australian) species is an aggressive alien invasive species in non-arid areas, but fortunately it can not germinate in arid areas, hence its introduction into runoff harvesting systems in arid areas for firewood production does not cause an uncontrolled invasion, since the plant cannot spread out of the runoff catchment and into the dryer areas outside it. Israeli research in the Yatir area found that non-fruit tree species of arid origin such as *Acacia negevensis* respond better to harvested runoff in degraded arid areas than do species of semi-arid origin, and are more useful in arresting soil erosion.

Israeli and Palestinian afforestation activities also recognized the cultural significance of non-fruit bearing trees, which became the focus of Palestinian tree-planting campaigns in public gardens and recreational parks and along roadsides. Thousands of saplings were planted in cooperation with schools and local communities throughout the Hebron area, with public awareness messages stressing the cultural and aesthetic value of trees as well as their role in environmental stewardship.

The tree-planting ethos inspired earlier *afforestation* efforts in Israel during the 1960s and 1970s at Yatir, and the Israeli Watershed Management team analyzed the pros and cons of those past efforts. The team concentrated much of its afforestation efforts at a 3,000 hectare site in Yatir, and found that only 3 percent of the rainfall in the watershed becomes surface runoff, and that *none* of it escapes the watershed in flash floods. Soil erosion in the watershed is therefore negligible. Since the trees were found to transpire 60 percent of the rainfall, 40 percent remained available to wild indigenous vegetation within the forest.

Dryland afforestation was found to be instrumental in soil conservation, and in controlling destructive and wasteful flash floods – but at the cost of reducing indigenous non-woody biodiversity. Afforestation in the Yatir area reduced the productivity of indigenous annual plants by 48 percent, and the productivity of perennial shrubs by 93 percent, as compared to non-grazed and non-afforested parts of the Yatir area. A controlled field experiment carried out in the forest demonstrated that arboreal and herbaceous vegetative cover both reduce runoff and increase soil moisture, and that mixed arboreal–herbaceous cover is slightly more effective in doing so. The finding led to the conclusion that sustainable rangeland management is likely to be as effective in soil and water conservation as replacing rangeland with forest, though the combination of planted trees and indigenous flora is likely to prove most effective.

The ***carbon sequestration*** implications of dryland afforestation lend the practice a novel economic potential in addition to its fuelwood, forage, and recreational values (Figure 60). The Israeli team valued the carbon sequestration returns to afforestation at US$18 per hectare annually on the global carbon market. Pruning afforested areas for fuelwood and fire prevention was valued at $63 per hectare per year, and forage production was valued at $43 per hectare per year. Finally the recreational value of afforested areas was valued at $0.7 per hectare per year based on travel cost methods by which an average tourist's willingness to pay for travel to the site is estimated. On the other hand, an Israeli socio-economic survey established that local Bedouins earn less than 1 percent of their overall income from forest grazing. Yet this grazing is quite valuable to forest managers as a measure to prevent forest fires, which are often ignited by the annual under-story if it is not grazed in spring but remains as standing-dead fuel during the dry season (Figure 61).

Figure 60: Exploring the pros and cons for arid afforestation. Afforested (back) and non-afforested (front) areas of the Yatir Watershed in the spring growing season; Israel.

Figure 61: Summer, non-afforested vegetation is mostly standing-dead. The Israeli WSM team harvests the annual production of the indigenous vegetation cover.

Taken together, the combined annual monetary benefits derived from forests were estimated to be double the annual cost of forest maintenance. But the economic value of the water used by the forest proved to be higher than the value of the forest itself. This negative equation of dryland afforestation can be offset by the non-industrial MENA countries through income to be generated under the Carbon Finance Mechanism within the framework of the Kyoto Protocol, especially given the relatively high carbon sequestration potential of this afforestation.

The Tunisian Watershed Management program saw notable success in using tree-bush combinations to ***fix dunes*** in its rangeland restoration efforts. A large, sandy traditional rangeland in the Gabès area had been overgrazed to the point that the land base was seriously destabilized, with widespread degeneration into shifting dunes. The Tunisian team collaborated with the Ministry of Agriculture and the *Institut National de la Recherche en Génie Rural Eaux et Forêts* (INRGREF) in implementing the restoration program with the participation of local land users. Water harvesting methods included irrigation using water from local wells (with 17 grams salinity per liter), and areas of sand were overlaid with a checkerboard pattern of palm leaves and straw to prepare the soil for planting. Drought- and salt-tolerant bushes and trees, including date palms and olives were then planted to serve as dune stabilizers, in addition to their roles as sources of fruit, forage, and fuelwood. By the end of the sixth year of the project, which included five years of drought, sand drift was totally arrested, natural vegetation spontaneously emerged, and overall range productivity increased four-fold.

Genetic Resources and Biodiversity

The Palestinian Watershed Management team surveyed the Hebron area to assess the status of medicinal plants and to compile a wild flower guide including photos of 300 local species. The Tunisian